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Vol. VIII SEPTEMBER, 1897 No. 9

MODIFICATION OF THE GREAT LAKES BY EARTH MOVEMENT *

By G. K. Gilbert,

U. S. Geological Survey

The history of the Great Lakes practically begins with the melting of the Pleistocene ice-sheet. They may have existed before the invasion of the ice, but if so their drainage system is unknown. The ice came from the north and northeast, and spreading over the whole Laurentian basin invaded the drainage districts of the Mississippi, Ohio, Susquehanna, and Hudson. During its waning there was a long period when the waters were ponded between the ice front and the uplands south of the Laurentian basin, forming a series of glacial lakes whose outlets were southward through various low passes. A great stream from the Erie basin crost the divide at Fort Wayne to the Wabash river. A river of the magnitude of the Niagara afterward flowed from the Michigan basin across the divide at Chicago to the Illinois river; and still later the chief outlet was from the Ontario basin across the divide at Rome to the Mohawk valley.

The positions of the glacial lakes are also markt by shore-lines, consisting of terraces, cliffs, and ridges, the strands and spits formed by their waves. Several of these shore-lines have been traced for hundreds of miles, and wherever they are thoroughly studied it is found that they no longer lie level but have gentle slopes toward the south and southwest. Formed at the edges of

*Publisht by permission of the Director of the United States Geological Survey. A more extended paper, of similar scope, entitled "Recent earth movement in the Great Lakes region," will appear in the Eighteenth Annual Report of the Survey.

water surfaces, they must originally have been level, and their present lack of horizontality is due to unequal uplift of the land. The region has been tilted toward the south-southwest. The different shore-lines are not strictly parallel, and their gradients vary from place to place, ranging from a few inches to three or four feet to the mile.

The epoch of glacial lakes, or lakes partly bounded by ice, ended with the disappearance of the ice-field, and there remained only lakes of the modern type, wholly surrounded by land. These were formed one at a time, and the first to appear was in the Erie basin. It was much smaller than the modern lake, because the basin was then comparatively low at the northeast. Its outline is approximately shown by the inner dotted line of the accompanying map. Instead of reaching from the site

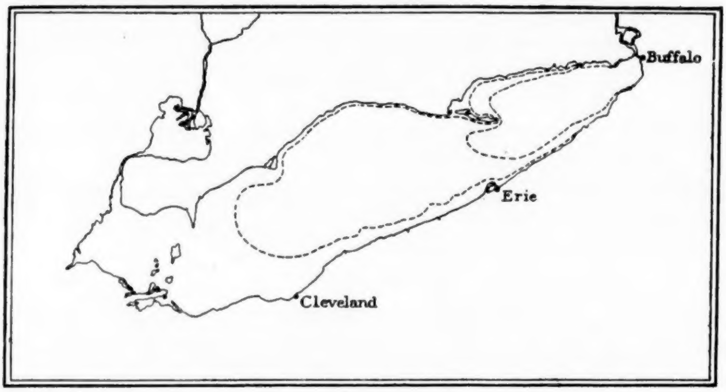

FIG. I—ANCIENT AND MODERN OUTLINES OF LAKE ERIE
The broken lines show the positions of the shores at two epochs of the lake's history

of Buffalo to the site of Toledo, it extended only to a point opposite the present city of Erie, and it was but one-sixth as large as the modern lake. Since that time the land has gradually risen at the north, canting the basin toward the south, and the lake has gradually encroacht upon the lowlands of its valley. At a date to be presently mentioned as the Nipissing, the western end of the lake was opposite the site of Cleveland, as indicated by another dotted line.

The next great lake to be releast from the domination of the ice was probably Ontario, though the order of precedence is here not equally clear. Before the Ontario valley held a land-bound lake it was occupied by a gulf of the ocean. Owing to the different attitude of the land, the water surface of this gulf was not

parallel to the present lake surface but inclined at an angle. In the extreme northeast, in the vicinity of the Thousand Islands, the marine shores are nearly 200 feet above the present water level, but they descend southward and westward, passing beneath the lake level near Oswego, and toward the western end of the lake must be submerged several hundred feet. This condition was of short duration, and the rising land soon divided the waters, establishing Lake Ontario as an independent water body. The same peculiarity of land attitude which made the original Erie a small lake served to limit the extent of Ontario, but the restriction was less in amount because of the steeper slopes of the Ontario basin. Here again the southward tilting of the land had the effect of lifting the point of outlet and enlarging the expanse of the lake.

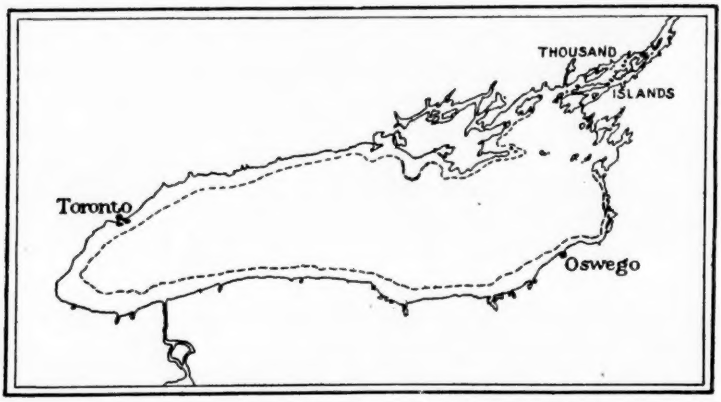

FIG. 2—ANCIENT AND MODERN OUTLINES OF LAKE ONTARIO
The broken line shows the original extent of the lake

There is some reason to think that the upper lakes, Huron, Michigan, and Superior, were at first open to the sea, so as to constitute a gulf, but the evidence is not so full as could be desired. When the normal lacustrine condition was establisht they were at first a single lake instead of three, and the outlet, instead of being southward from Lake Huron, was northeastward from Georgian bay, the outlet river following the valleys of the Mattawa and Ottawa to the St Lawrence. The triple lake is known to us chiefly through the labors of F. B. Taylor, who has made extensive studies of its shore-line. This line, called the Nipissing shore-line, is not wholly submerged, like the old shores of lakes Erie and Ontario, but lies chiefly above the

present water surfaces. It has been recognized at many points about Lake Superior and the northern parts of lakes Huron and Michigan, and measurements of its height show that its plane has a remarkably uniform dip, at 7 inches per mile, in a south-southwest direction, or, more exactly, S. 27° W. As will be seen by the accompanying map, reproduced from Taylor, it crosses the modern shore-line of Lake Superior near its western end, thereby passing beneath the water surface; and it similarly passes below the surface of Lake Michigan near Green bay, and below the

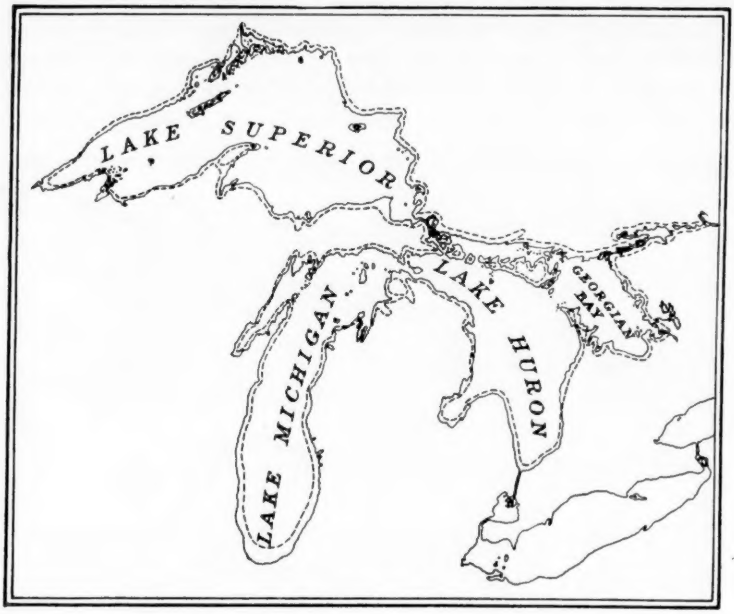

FIG. 3—THE NIPISSING GREAT LAKE (AFTER TAYLOR)
Its boundaries are shown by the broken line

surface of Lake Huron just north of Saginaw bay. The southward tilting of the land, involving the uplift of the point of outlet, increast the capacity of the basin and the volume of the lake, gradually carrying the coast-line southward in Lake Huron and Lake Michigan until finally it reacht the low pass at Port Huron and the water overflowed via the St Clair and Detroit channels to Lake Erie. The outlet by way of the Ottawa was then abandoned, and a continuance of the uplift caused the water to slowly recede from its northern shores. This change after a time separated Lake Superior from the other lakes, bring-

ing the St Marys river into existence, and eventually the present condition was reacht.

These various changes are so intimately related to the history of the Niagara river that the Niagara time estimates, based on the erosion of the gorge by the cataract, can be applied to them. Lake Erie has existed approximately as long as the Niagara river, and its age should probably be reckoned in tens of thousands or hundreds of thousands of years. Lake Ontario is much younger. All that can be said of the beginning of Great Lake Nipissing is that it came long after the beginning of Lake Erie, but the date of its ending, through the transfer of outlet from the Mattawa to the St Clair, is more definitely known. That event is estimated by Taylor to have occurred between 5,000 and 10,000 years ago.*

The lake history thus briefly sketcht is characterized by a progressive change in the attitude of the land, the northern and northeastern portions of the region becoming higher, so as to turn the waters more and more toward the southwest. The latest change, from Great Lake Nipissing to Great Lakes Superior, Michigan, and Huron, involving an uplift at the north of more than 100 feet, has taken place within so short a period that we are naturally led to inquire whether it has yet ceast. Is it not probable that the land is still rising at the north and the lakes are still encroaching on their southern shores? J. W. Spencer, who has been an active explorer of the shore-lines of the glacial lakes and has given much study to related problems, is of opinion that the movements are not complete, and predicts that they will result in the restoration of the Chicago outlet of Lake Michigan and the drying of Niagara.†

The importance of testing this question by actual measurements was imprest upon me several years ago, and I endeavored to secure the institution of an elaborate set of observations to that end. Failing in this, I undertook a less expensive investigation, which began with the examination of existing records of lake height as recorded by gage readings, and was continued by the establishment of a number of gage stations in 1896. To understand fully the nature of this investigation it is necessary to consider the difficulties that arise from the multifarious motions to which the lake water is subject.

*Studies in Indiana Geography, X. A short history of the Great Lakes. Terre Haute, 1897.

† Proc. Am. Ass. Adv. Sci., vol. LIII, 1894, p. 246.

If the volume of a lake were invariable, and if its water were in perfect equilibrium under gravity, its surface would be constant and level, and any variation due to changes in the height of the land could be directly determined by observations on the position of the water surface with reference to the land; but these conditions are never realized in the case of the Great Lakes, where the volume continually changes and the water is always in motion. The investigator therefore has to arrange his measurements so as to eliminate the effect of such changes.

Consider first the influence of wind. The friction of the wind on the water produces waves. These are temporary and practically cease in periods of calm; the perpetual ground-swell of the ocean is not known on the lakes. The friction of the wind on the water also drives the water forward, producing currents. The water thus driven against the lee shores returns in undercurrents, but the internal friction of the water resists and delays the return, and there is consequently a heaping of the water against lee shores and a corresponding lowering of its level on other shores. During great storms these differences amount to several feet, reaching a maximum in Lake Erie; in October, 1886, a westerly gale is reported to have raised the water 8 feet at Buffalo and deprest it 8 feet at Toledo.* For light winds the changes of level are much smaller, but they are nevertheless appreciable, and they have even been detected in the case of the gentle " land and sea " breezes which in calm weather are created by the diurnal cycle of temperature change on the land.

The water is also sensitive to atmospheric pressure. If the air prest equally on all parts of the lake surface the equilibrium of the water would not be disturbed; but its pressure is never uniform. As shown by the isobars on the daily weather map, there are notable differences of pressure from point to point, and within the length of one of the Great Lakes these often amount to several tenths of a barometric inch. A column of mercury 0.1 inch high weighs as much as a column of water 1.3 inches high; and whenever the atmospheric pressure at one point on a lake exceeds the pressure at another point by the tenth of a barometric inch, the water level at the first point is, in consequence, 1.3 inches lower than the water level at the second point. When a cumulus cloud forms over the water there is a reaction on the

* Science, vol. VIII, pp. 34, 391. The effect of a storm in October, 1893, is ably discust by Wm. T. Blount, in Ann. Rept. Chief of Engineers, U. S. A., for 1894, part 6, pp. 3431-3435.

water, disturbing its equilibrium, and the passage of a thunderstorm often produces oscillations attracting the attention of even the casual observer. Such sudden and temporary variations of pressure give rise to waves analogous to those caused by a falling pebble, except that they are broad and low, and these waves not only travel to all parts of a lake but are continued by reflection, so that a local storm at one point is felt in the water surface at all points and for a considerable period. The passage of the greater atmospheric waves associated with ordinary cyclonic storms and the impulses given by winds are also able to set the whole body of the lake in motion, so that it sways from side to side or end to end like the swaying water in a tub or basin, and these swaying motions are of indefinite continuance. In the deeper lakes, and probably in all the lakes, they are so enduring as to bridge over the intervals from impulse to impulse. Such oscillations, which appear at any point on the coast as alternate risings and fallings of the water, with periods ranging from a few minutes to several hours, are called *seiches*. Their amplitude is usually a few inches, but at the ends of lakes is sometimes a foot or more.

The lakes, like the ocean, are swayed by the attractions of the sun and moon. Their tides are much smaller than those of the ocean, and are even small as compared to the seiches, but they are still measurable. At Milwaukee the lunar tide rises and falls more than an inch and the solar tide a half inch. At Chicago and Duluth each tide amounts to an inch and a half, and their combination at new and full moon to three inches.

Water is continually added to each lake by rivers and creeks, but the rate is not uniform. Usually a few freshets, occurring within two or three weeks, contribute more water than comes during all the remainder of the year. Water is also added in an irregular way by rain and snow falling directly on the lake. It is subtracted by evaporation, the rate of which varies greatly, and by overflow, which varies within moderate limits. The volume of water contained in the lake, being subject to these variable gains and losses, is itself inconstant, and the general height of the water surface therefore oscillates. In average years the range of variation for Lake Superior is 12 inches; for lakes Michigan and Huron, 12 inches; for Lake Erie, 14 inches, and for Lake Ontario, 17 inches. Low water occurs normally in January or February for all the lakes except Superior, where it occurs in March. High water is reacht sooner in the lower lakes, June

being the usual month for Ontario, June or July for Erie, July for Michigan and Huron, and August or September for Superior. Fig. 4 shows the character of the annual oscillations, as given by averages of long series of years.

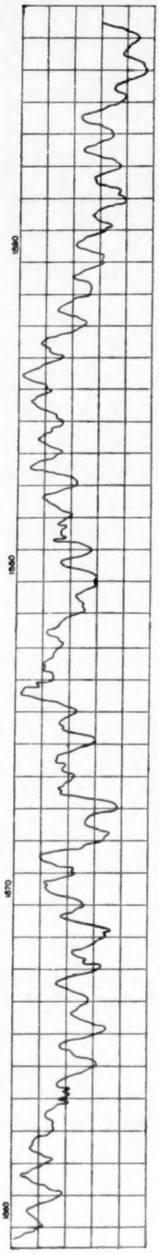

FIG. 4—ANNUAL OSCILLATIONS OF THE SURFACES OF THE LAURENTIAN LAKES

Compiled from monthly means publisht by the Chief of Engineers, U. S. A. Each vertical space represents six inches. The observations for Lake Superior cover the period 1862-1895; for Michigan-Huron, 1860-1895; for Erie, 1855-1895; for Ontario, 1860-1895

In a wet year more water enters the lake than leaves it, and there is a net rise of the surface; in a dry year there is a net fall. A series of wet years produce exceptionally high water, and a series of dry years exceptionally low, so that the entire range of water height is considerably greater than the annual range. The recorded range for lakes Superior, Michigan, and Huron is between 5 and 6 feet; for Erie and Ontario, between 4 and 5 feet.

The accompanying diagram (Fig. 5) of the oscillations of Lake Michigan illustrates the annual cycle and also the progressive changes from year to year. Being compiled from monthly means of gage readings, it does not show tides and seiches nor the oscillations of short period.

These various oscillations of the water, though differing widely in amplitude, rate, and cause, yet coexist, and they make the actual movement of the water surface highly complex. The complexity of movement seriously interferes with the use of the water plane as a datum level for the measurement of earth movements, and a system of observations for that purpose needs to be planned with much care. The main principles of such a system are, however, simple, and may readily be stated. The most important is that the direct measurement of the heights of individual points should not be attempted, but comparison should always be made between two points, their relative height being measured by means of the water surface used as a leveling instrument.

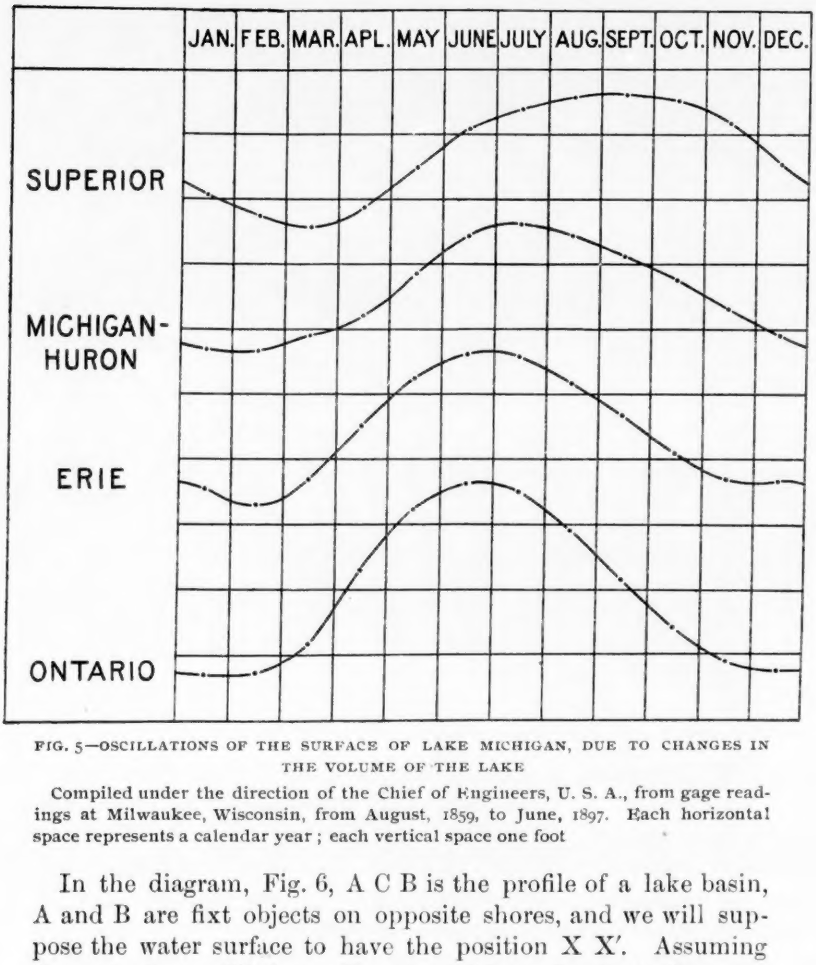

FIG. 5—OSCILLATIONS OF THE SURFACE OF LAKE MICHIGAN, DUE TO CHANGES IN THE VOLUME OF THE LAKE

Compiled under the direction of the Chief of Engineers, U. S. A., from gage readings at Milwaukee, Wisconsin, from August, 1859, to June, 1897. Each horizontal space represents a calendar year; each vertical space one foot

In the diagram, Fig. 6, A C B is the profile of a lake basin, A and B are fixt objects on opposite shores, and we will suppose the water surface to have the position X X′. Assuming the water in equilibrium, all parts of this surface have the same height. If the height of A above the water at X be accurately measured by the surveyor's level, and the height of B above the water at X′ be similarly measured, then the difference between these two measurements gives the difference in height between A and B. After an interval of some years or decades the work

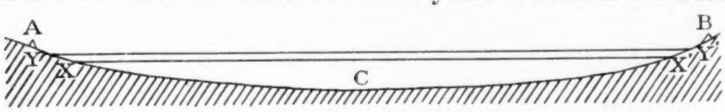

FIG. 6—DIAGRAM ILLUSTRATING THE METHOD OF USING A LAKE SURFACE FOR THE DISCOVERY AND MEASUREMENT OF EARTH MOVEMENTS

is repeated. The water surface then has some different position, Y Y′, and the heights measured are of A above Y and of B above Y′. The difference between the two heights gives again the relative height of A and B; and if earth movement has tilted the basin toward A or B, the change in their relative height may be shown by the difference in the two results of measurement.

As the water is in fact not still, but in continual motion, the mere running of lines of level from A and B to the water does not suffice, and it is necessary to determine from observations on the oscillating water surface what would be its position if still. Such observations are made by means of gages. These are of various forms, but each consists essentially of a fixt point, or zero, close by the water, and a graduated scale by means of which the vertical distance of the water surface from the zero is measured.

Changes in the volume of the lake influence all parts of its surface equally and at the same time. To eliminate their effects from the measurements it is only necessary that the gage observations at the two stations be simultaneous. The effects of wind waves can be prevented by breakwaters. Disturbances due to currents propelled by strong winds can be avoided by choosing times when there is little wind. The effects of light winds can be approximately eliminated by taking the average of many observations, and so can the effects of seiches and tides. The effects of differences of atmospheric pressure can be computed from barometric measurements of air pressure, and the proper corrections applied. It is also possible, by the discussion of long series of observations at each station, to determine the local tidal effects and afterward apply corrections; and the land and sea breeze effect may be treated in the same way.

In the investigation I was able to make, consideration was given to these various sources of error, but it was not practicable to take all desirable measures for avoidance or correction, because the reading of gages was only partly under my control. Gage stations have been establisht on the Great Lakes at various times and at various places, and the records of readings have been preserved. In some cases the zeros of gages were connected by leveling with bench marks of a permanent character, and in a few instances the gages themselves are stable and enduring structures. The most important body of information of this character is contained in the archives of the United States Lake Survey, which were placed at my service by the Chief of Engineers, U. S. A. By

searching the records I was able to select certain pairs of stations at which the relative heights of permanent points on the shore (equivalent to A and B of the diagram) had been practically determined twenty or more years ago. At some of these stations gages are still read; at others I establisht gages and ran the leveling lines necessary to connect them with the old benches. At all of them observations were maintained from July to October, 1896, and these observations, in combination with the levelings, afforded measurements that could be compared with those made earlier so as to discover changes due to earth movement.

It will not be necessary to give here the details of observation and computation, as they are fully set forth in a paper soon to

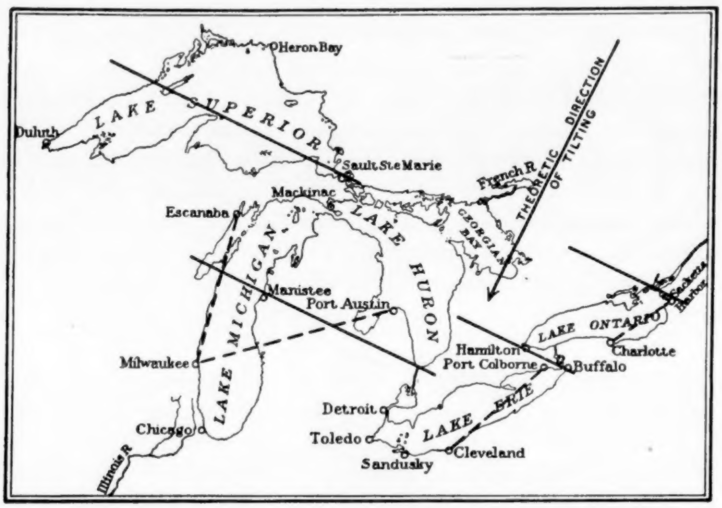

FIG. 7—MAP OF THE GREAT LAKES, SHOWING PAIRS OF GAGING STATIONS AND ISOBASES OF OUTLETS

The isobases are markt by full lines. Broken lines show the pairs of stations

be printed by the Geological Survey, but the general scope of the work may be briefly outlined. As the tilting shown by the geologic data was toward the south-southwest, stations were, so far as possible, selected to test the question of motion in that direction. The most easterly pair were Sacketts Harbor and Charlotte, New York, connected by the water surface of Lake Ontario (see map, Fig. 7). From observations by the U. S. Lake Survey in 1874, it appeared that a bench mark on the old light-house in Charlotte was then 18.531 feet above a certain point on the Masonic Temple in Sacketts Harbor. In 1896 the measurement was re-

peated, and the difference found to be 18.470 feet, the point at Sacketts Harbor having gone up, as compared to the point at Charlotte, 0.061 foot, or about three-fourths of an inch. Similarly it was found that between 1858 and 1895 a point in Port Colborne, at the head of the Welland canal, as compared to a point in Cleveland, Ohio, rose 0.239 foot, or nearly three inches. Between 1876 and 1896 a point at Port Austin, Michigan, on the shore of Lake Huron, as compared to a point in Milwaukee, on the shore of Lake Michigan, rose 0.137 foot, or one and one-half inches; and in the same period a point in Escanaba, at the north end of Lake Michigan, as compared to the same point in Milwaukee, rose 0.161 foot, or about two inches.

There is no one of these determinations that is free from doubt; buildings and other structures on which the benches were markt may have settled, mistakes may have been made in the earlier leveling, when there was no thought of subjecting the results to so delicate a test, and there are various other possible sources of error to which no checks can be applied; but the fact that all the measurements indicate tilting in the direction predicted by theory inspires confidence in their verdict. This confidence is materially strengthened when the numerical results are reduced to a common unit and compared.

Summary of Distances, Time Intervals, and Measurements of Differential Earth Movements

Pairs of stations.	Direct distance.	Distance in direction S. 27° W.	Interval between dates of measurement.	Change in relative height.	Change per 100 miles per century.	Probable errors of quantities in last column.
	Miles.	*Miles.*	*Years.*	*Feet.*	*Feet.*	*Feet.*
Sacketts Harbor and Charlotte...	86	76	22	.061	.37	.18
Port Colborne and Cleveland.......	158	141	37	.239	.46	.11
Port Austin and Milwaukee......	259	176	20	.137	.39	.09
Escanaba and Milwaukee.........	192	186	20	.161	.43	.06
				Mean......	.41	
				Weighted mean......	.42	± .05

The stations of the several pairs are at different distances apart, the directions of the lines connecting them make various angles with the theoretic direction of tilting, and the time intervals separating the measurements are different. To reduce the results to common terms I have computed from each the rate of tilting it implies in the theoretic direction, S. 27° W. In the sixth column of the preceding table the rate is exprest as the change in relative height of the ends of a line 100 miles long during a century.

Compared in this way, the results are remarkably harmonious, the computed rates of tilting ranging only from 0.37 foot to 0.46 foot per 100 miles per century; and in view of this harmony it is not easy to avoid the conviction that the buildings are firm and stable, that the engineers ran their level lines with accuracy, that all the various possible accidents were escaped, and that we have here a veritable record of the slow tilting of the broad lake-bearing plain.

The computed mean rate of tilting, 0.42 foot per 100 miles per century, is not entitled to the same confidence as the fact of tilting. Its probable error, the mathematical measure of precision derived from the discordance of the observational data, is rather large, being one-ninth of the whole quantity measured. Perhaps it would be safe to say that the general rate of tilting, which may or may not be uniform for the whole region, falls between 0.30 and 0.55 foot.

While the credit of formulating the working hypothesis or geologic prediction which has thus been verified by measurement belongs to Spencer, it is proper to note that the fundamental idea of modern differential earth movement in the Great Lakes region was announced much earlier by G. R. Stuntz, a Wisconsin surveyor. In a paper communicated to the American Association for the Advancement of Science in 1869, he cites observations tending to show that in 1852–'53 the water of Lake Superior stood abnormally high at the west end while it was unusually low at the east, and he infers that the land is not stable.

The geographic effects of the tilting are of scientific and economic importance. Evidently the height of lake water at a lake's outlet is regulated by the discharge and is not affected by slow changes in the attitude of the basin; but at other points of the shore the water advances or retreats as the basin is tipt. Consider, for example, Lake Superior. On the map (Fig. 7) a line has been drawn through the outlet at the head of St Marys river in a direction at right angles to the direction of tilting. All

points on this line, called the *isobase* of the outlet, are raised or lowered equally by the tilting and are unchanged with reference to one another. All points southwest of it are lowered, the amount varying with their distances from the line, and all points to the northeast are raised. The water, always holding its surface level and always regulated in volume by the discharge at the outlet, retreats from the rising northeast coasts and encroaches on the sinking southwest coasts. Assuming the rate of tilting to be 0.42 foot per 100 miles per century, the mean lake level is rising at Duluth 6 inches per century and falling at Heron bay 5 inches. Where the isobase intersects the northwestern shore, which happens to be at the international boundary, there is no change.

Lake Ontario lies altogether southwest of the isobase of its outlet, and the water is encroaching on all its shores. The same tilting that enlarged it from the area markt by the dotted line of figure 2 is still increasing its extent. The estimated vertical rise at Hamilton is 6 inches per century. The whole coast of Lake Erie also is being submerged, the estimated rate at Toledo and Sandusky being 8 or 9 inches per century.

The isobase of the double Lake Huron-Michigan passes southwest of Lake Huron and crosses Lake Michigan. All coasts of Lake Huron are therefore rising as compared to the outlet, and the consequent apparent lowering of the mean water surface is estimated at 6 inches per century for Mackinac and at 10 inches for the mouth of the French river on Georgian bay. In Lake Michigan the line of no change passes near Manistee, Michigan. At Escanaba the estimated fall of the water is 4 inches per century; at Milwaukee the estimated rise is 5 or 6 inches, and at Chicago between 9 and 10 inches.

These slow changes of mean water level are concealed from ordinary observation by the more rapid and impressive changes due to variations of volume, but they are worthy of consideration in the planning of engineering works of a permanent character, and there is at least one place where their influence is of moment to a large community. The city of Chicago is built on a smooth plain little above the high-water level of Lake Michigan. Every decade the mean level of the water is an inch higher, and the margin of safety is so narrow that inches are valuable. Already the older part of the city has lifted itself several feet to secure better drainage, and the time will surely come when other measures of protection are imperatively demanded.

Looking to the more distant future, we may estimate the date at which the geographic revolution prophesied by Spencer will occur. Near Chicago, as already mentioned, is an old channel made by the outlet of a glacial lake. The bed of the channel at the summit of the pass is about 8 feet above the mean level of Lake Michigan and 5 feet above the highest level. In 500 or 600 years (assuming the estimated rate of tilting) high stages of the lake will reach the pass, and the artificial discharge by canal will be supplemented by an intermittent natural discharge. In 1,000 years the discharge will occur at ordinary lake stages, and after 1,500 years it will be continuous. In about 2,000 years the discharge from Lake Michigan-Huron-Erie, which will then have substantially the same level, will be equally divided between the western outlet at Chicago and the eastern at Buffalo. In 2,500 years the Niagara river will have become an intermittent stream, and in 3,000 years all its water will have been diverted to the Chicago outlet, the Illinois river, the Mississippi river, and the Gulf of Mexico.

THE TORONTO MEETING OF THE BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

If the British Association for the Advancement of Science has never yet done itself the honor of electing a geographer as its President, it at least is not open to the reproach of neglecting so important a department of knowledge as that which is concerned with the distribution of the human race and the manifold conditions of its environment. Throughout its entire history of 67 years the Association has given geography a prominent place in its proceedings, and there have been few distinguished explorers who have not reserved some of their most interesting and important utterances for the Geographical Section of this great scientific body. Just 40 years ago, in the city of Dublin, it was to see and hear Livingstone that people crowded into the hall assigned to Section E. Fifteen years later, at Brighton, before an equally large and brilliant assemblage, Mr Stanley narrated the thrilling story of his search for the great missionary-traveler in the wilds of equatorial Africa, and almost every Arctic explorer and every seeker for the mysterious sources of the Nile and every daring adventurer who has penetrated the recesses of

the great Asiatic plateau has modestly narrated the story of his travels and his discoveries before the British Association.

If the recent Toronto meeting will not be remembered for any dramatic incidents or other highly sensational features, it was in many respects a notable gathering and by no means lacking in important contributions to geographic science. The address of the President of the Geographical Section, Mr J. Scott Keltie, LL. D., Joint Secretary of the Royal Geographical Society and Editor of the Geographical Journal and of the Statesman's Year-Book, dealt with the geographic problems of the future and set forth in admirable and most instructive array the various regions of the globe that are still wholly or in large part unexplored. This address is published, with but very slight abridgment, in the following pages, as a matter not merely of general interest, but of especial value to teachers and geographic students who find it difficult to keep abreast of geographic research in the more remote parts of the world.

Dr Keltie's address was delivered on August 19, and in the afternoon of the same day Sir George Scott Robertson, the Hero of Chitral, described Kafiristan and the Kafirs; Mr E. G. Ravenstein, of London, presented the sixth report of the Committee on the Climatology of Africa, a subject of great interest in view of the recent extension of European territory on that continent; Mr E. Delmar Morgan, of London, read a paper on Nova Zembla and its Physical Geography, summarizing the results of recent Russian investigations and presenting the conclusion that the country is now undergoing a new process of glaciation that will convert it into an icy wilderness; Mr B. Leigh Smith, also of London, spoke on Recent Temperature Observations off Spitzbergen, and a voluminous report was presented on The Position of Geography in the Educational System of Great Britain.

On the following day the proceedings of the Geographic Section included a paper by Prof. Richard E. Dodge, of the Teachers College, New York, on Scientific Geography for Schools, which was a plea for the more scientific teaching of geography in the public schools and for systematic coöperation in the bringing about of a much-needed improvement; a paper by Col. F. Bailey, of Edinburgh, on Forestry in India, showing the serious results of forest denudation in that country and the measures that have been adopted to remedy the evil; a Scheme of Geographical Classification, by Dr Hugh Robert Mill, of London; a paper by Mr Vaughn Cornish, on The Distribution of Detritus by the Sea;

a paper by Mr E. G. Ravenstein, on The Kongo and the Cape of Good Hope, 1482 to 1488, a narrative of one of the most interesting periods in the history of geographic exploration, and a communication by Prof. John Milne, of the Isle of Wight, on Certain Submarine Geological Changes, which was mainly an epitome of the article on Suboceanic Changes, published in the July and August numbers of the Geographical Journal.

On August 23 Mr Marcus Baker, of the U. S. Geological Survey, read a paper, the joint production of himself and Mr Gardiner G. Hubbard, President of the National Geographic Society, on the Geography of the United States and the Agencies employed in its Exploitation; General A. W. Greely presented a paper by Prof. F. H. Newell, Chief Hydrographer of the U. S. Geological Survey, on the Hydrography of the United States; Dr T. C. Mendenhall, President of the Worcester Polytechnic Institute and formerly Superintendent of the U. S. Coast and Geodetic Survey, and Mr Otto H. Tittmann, Assistant in charge of the Office of the Survey, discussed the geographic work of that important government bureau; Mr J. B. Tyrrell, of Ottawa, read a paper on the Barren Lands of Canada, by which title he designated the plains and prairies which stretch from Hudson bay to the Mackenzie river and from the coastline of the Arctic ocean southward to the region of civilization; Mr W. J. White read a paper on the Topographic Work of the Geological Survey of Canada; Prof. Charles D. Walcott, Director of the Geological Survey of the United States, presented a valuable communication on the geographical work of the institution over which he so ably presides, and Prof. Willis L. Moore, Chief of the U. S. Weather Bureau, discussed entertainingly and instructively the Climatology of the United States.

The proceedings of August 24 opened with an address by Mr F. C. Selous on the Economic Geography of Rhodesia, a region in which he has spent twenty-five years in elephant and lion hunting, but in which the ultimate destiny of a large part of the African continent is now being wrought out. This was followed by a Journey in Tripoli, by Mr J. T. Myers; Potamology as a Branch of Geography, by Prof. Albrecht Penck, of the University of Vienna; the Geographical Development of the Lower Mississippi, by Dr E. L. Corthell, of New York; Southeastern Alaska, by Mr Otto J. Klotz, of Ottawa; The First Ascent of Mt. Lefroy and Mt. Aberdeen, by Prof. H. B. Dixon, of Manchester; Mexico Felix and Mexico Deserta, by Mr O. H. Howarth,

of London, and The Direction of Lines of Structure in Eurasia, by Prince Kropotkin, an important paper written in a Russian prison and saved from destruction by the Russian Geographical Society after the escape of its author.

On August 25, the closing day of the meeting, Prof. W. M. Davis, of Harvard, spoke on the importance of geography as a university subject; General A. W. Greely read a paper by Mr Henry Gannett, Chief Geographer of the U. S. Geological Survey, on the Growth and Material Conditions of the United States, and Dr Mill and Prof. Penck exhibited a large number of views illustrative of geographic scenes and conditions.

While the foregoing represents the work of the Geographical Section, it by no means exhausts the list of subjects of interest to the student of geography that were discussed at the Toronto meeting. In the Section of Mathematics and Physics, on August 19, Prof. John Milne presented a report from the Committee on Seismological Observations, and exhibited, for the purpose of illustrating the nature of certain recent discoveries, the wonderfully delicate instruments that are used in locating breakages in submarine cables. On the same day, in the Section of Geology, Prof. J. C. Branner, of Stanford University, discussed The Former Extension of the Appalachians across Mississippi, Louisiana, and Texas, and Dr F. D. Adams demonstrated the plasticity of rocks. Again, in the Section of Mathematics and Physics, on August 20, Mr Alexander Johnson, of McGill University, discussed the project of an Imperial Hydrographic Survey, and at the Horticultural Pavilion Prof. H. O. Forbes, of Liverpool, lectured on British New Guinea, its People, and the Problems which the Region offers to Geologists and Naturalists.

In the Section of Meteorology, on August 23, Mr F. Napier Denison, of the Toronto Observatory, discussed the Great Lakes as a Sensitive Thermometer; Mr John Hopkinson read a paper on The Monthly and Annual Rainfall in the British Empire during the last Twenty Years, Dr Van Rijckevorsel, of Rotterdam, discussed the Temperature of Europe, laying stress on the influences originating in western Asia on the east and in or beyond the Atlantic ocean on the west; Mr R. F. Stupart, of the Toronto Meteorological Department, read a paper on The Climatology of Canada, and Mr R. G. Haliburton, a learned member of the Canadian Bar, discussed November Meteors and November Flood Traditions. In the evening Prof. John Milne lectured before the Association in general session on Earthquakes and

Volcanoes, an exceptionally large and distinguished audience being attracted by the fame of the man who announced in England on the day of its occurrence the terrible earthquake which visited Japan in June, 1896.

The Anthropological Section also presented many attractions to the geographer, especially on August 23, when the proceedings included a paper by Mr B. Sulte on the Origin and Characteristics of the French-Canadians, an account of the Seri Indians, by Prof. W J McGee, Acting President of the American Association, and a long discussion on the Evidences of American-Asiatic Contact, opened by Prof. F. W. Putnam, of Harvard.

It will readily be seen from the foregoing that the Toronto meeting of the British Association was the occasion of many notable contributions to geographic science, and no apology will be offered for the presentation in forthcoming numbers of The National Geographic Magazine of abridgments of such of them as are of greatest value and are available for the purpose.

J. H.

THE GREAT UNMAPPED AREAS ON THE EARTH'S SURFACE AWAITING THE EXPLORER AND GEOGRAPHER*

By J. Scott Keltie, LL. D.,

Secretary to the Royal Geographical Society, Editor of the Geographical Journal and of the Statesman's Year-Book, etc., etc.

We meet this year in exceptional circumstances. Thirteen years ago the British Association met for the first time in a portion of the empire beyond the limits of the British islands. During these thirteen years much has happened of the greatest interest to geographers, and if I attempted to review the progress which has been made during these years—progress in the exploration of the globe, progress in geographical research, progress in geographical education—I could not hope to do it to any purpose in the short time during which it would be right for a president to monopolize the attention of the Section.

But we have, at the same time, reached another stage in our history which naturally leads us to take stock of our progress in

*** Presidential address delivered before the Geographical Section of the British Association for the Advancement of Science, at Toronto, August 19, 1897.**

the past. We have all of us been celebrating the sixtieth year of the glorious reign of the Sovereign of whose vast dominions Canada and the United Kingdom form integral parts. The progress made during that period in our own department of science has been immense; it would take volumes to tell what has been done for the exploration of the globe.

The great continent of Africa has practically been discovered, for sixty years ago almost all but its rim was a blank. In 1837 enormous areas in North America were unexplored and much of the interior of South America was unknown. In all parts of Asia vast additions have been made to our knowledge; the maps of the interior of that continent were sixty years ago of the most diagrammatic character. The Australian interior was nearly as great a blank as that of Africa; New Zealand had not even been annexed. Need I remind you of the great progress which has been made during the period both in the North and South Polar areas, culminating in the magnificent achievement of Dr Nansen? It was just sixty years ago that the great Antarctic expedition under Sir James Ross was being organized; since that, alas! little or nothing has been done to follow up his work. Sixty years ago the science of oceanography, even the term, did not exist. It is the creation of the Victorian era, and may be said almost to have had its origin in the voyage of the *Challenger*, which added a new domain to our science and opened up inexhaustible fields of research.

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I have thought, then, that the most useful and most manageable thing to do on the present occasion will be to indicate briefly what, in my estimation, are some of the problems which geography has to attack in the future, only taking such glances at the past as will enable us to do this intelligibly.

ASIA

Turning to the continent of Asia, we find that immense progress has been made during the past sixty years. In the presidential address given sixty years ago Mr Hamilton says of Asia: "We have only a general knowledge of the geographical character of the Burman, Chinese, and Japan empires; the innumerable islands of the latter are still, except occasionally, inaccessible to European navigators. Geographers hardly venture on the most loose description of Tibet, Mongolia, or Chinese Tartary, Siam, and Cochin China." Since then the survey of India, one of the greatest

enterprises undertaken by any State, has been completed, and is being rapidly extended over Burma. But I need not remind you in detail of the vast changes that have taken place in Asia during these years and the immense additions that have been made to our knowledge of its geography. Exploring activity in Asia is not likely to cease, though it is not to be expected that its inhospitable center will ever be so carefully mapped as have been the mountains of Switzerland.

The most important desiderata, so far as pioneer exploration in Asia is concerned, may be said to be confined to two regions. In southern and central Arabia there are tracts which are entirely unexplored. It is probable that this unexplored region is in main a sandy desert. At the same time it is, in the south at least, fringed by a border of mountains whose slopes are capable of rich cultivation and whose summits the late Mr Theodore Bent found, on his last and fatal journey, to be covered with snow. In exploration, as in other directions, it is the unexpected that happens; and if any traveler cared to face the difficulties—physical, political, and religious—which might be met with in southern and central Arabia, he might be able to tell the world a surprising story.

The other region in Asia where real pioneer work still remains to be done is Tibet and the mountainous districts bordering it on the north and east. Lines of exploration have in recent years been run across Tibet by Russian explorers like Prjevalsky, by Rockhill, Prince Henry of Orleans, and Bonvalot, by Bower, Littledale, Wellby, and Malcolm. From the results obtained by these explorers we have formed a fair idea of this, the most extensive, the highest, and the most inhospitable plateau in the world. A few more lines run in well selected directions would probably supply geography with nearly all she wants to learn about such a region, though more minute exploration would probably furnish interesting details as to its geological history.

THE FORBIDDEN CITY

The region lying to the north of the Himalayan range and to the south of the parallel of Lhasa is almost a blank on the map, and there is ample room here for the enterprising pioneer. The forbidden city of Lhasa is at present the goal of several adventurers, though as a matter of fact we cannot have much to learn in addition to what has been revealed in the interesting narrative of the native Indian traveler, Chandra Das. The magnifi-

cent mountain region on the north and east of Tibet furnishes a splendid field for the enterprising explorer. Mrs Bishop recently approached it from the east, through Sze-chuen, and her description of the romantic scenery and the interesting non-Mongolian inhabitants leaves us with a strong desire to learn more. On the southeast of Tibet is the remarkable mountainous region, consisting of a series of lofty parallel chains, through which run the upper waters of the Yangtse, the Mekong, the Salwin, and the Irrawaddy. This last-named river, recent exploration has shown, probably does not reach far into the range. But it will be seen by a glance at a map that the upper waters of the other rivers are carried far into the heart of the mountains. But these upper-river courses are entirely conjectural and have given rise to much controversy. There is plenty of work here for the explorer, though the difficulties, physical and political, are great.

But besides these great unexplored regions there are many blanks to be filled up in other parts of Asia, and regions which, though known in a general way, would well repay careful examination. There is the mountain track between the Zarafshan river and the middle course of the Sarkhab, tributary of the Oxus, and the country lying between that and the Oxus. There is the great Takla-Makan desert in Chinese or Eastern Turkistan, part of which has recently been explored by Russian expeditions and by that young and indefatigable Swedish traveler, Dr Sven Hedin. It is now one of the most forbidding deserts to be found anywhere, but it deserves careful examination, as there are evidences of its once having been inhabited, and that at no very remote period. It is almost surrounded by the Tarim, and on its eastern edge lies Lob-nor, the remarkable changes in which have been the subject of recent investigation. As readers of Dr Nansen's Voyage of the *Fram* will remember, the Siberian coast is most imperfectly mapped. Of course it is a difficult task, but it is one to which the Russian government ought to be equal. China has on paper the appearance of being fairly well mapped; but as a matter of fact our knowledge of its mountain ranges and of its great river courses is to a large extent extremely vague. All this awaits careful survey. In northeastern Manchuria and in many parts of Mongolia there are still blanks to be filled up and mountain and river systems to be surveyed. In the Malay peninsula and in the great array of islands in the east and southeast of Asia—Sumatra, Borneo, the Philippines—much work still remains to be done. Thus for the coming century there will be abundance of

work for explorers in Asia and plenty of material to occupy the attention of our geographical societies.

DARKEST AFRICA

Coming to the map of Africa, we find the most marvelous transformation during the last sixty years, and mainly during the last forty years, dating from Livingstone's memorable journey across the continent. Though the north of Africa was the home of one of the oldest civilizations, and though on the shores of the Mediterranean Phœnicians, Carthaginians, Greeks, and Romans were at work for centuries, it has only been within the memory of many of us that the center of the continent, from the Sahara to the confines of Cape Colony, has ceased to be an unexplored blank. This blank has been filled up with bewildering rapidity. Great rivers and lakes and mountains have been laid down in their main features, and the whole continent, with a few unimportant exceptions, has been parceled out among the powers of Europe; but much still remains to be done ere we can form an adequate conception of what is in some respects the most interesting and the most intractable of the continents. Many curious problems still remain to be solved. The pioneer work of exploration has to a large extent been accomplished; lines have been run in all directions; the main features have been blocked out; but between these lines the broad meshes remain to be filled in, and to do this will require many years of careful exploration. However, there still remain one or two regions that afford scope for the adventurous pioneer.

To the south of Abyssinia and to the west and northwest of Lake Rudolf, on to the Upper Nile, is a region of considerable extent, which is still practically unknown. Again, in the western Sahara there is an extensive area, inhabited mainly by the intractable Tuaregs, into which no one has been able to penetrate, and of which our knowledge is extremely scanty. Even in the central Sahara there are great areas which have not been traversed, while in the Libyan desert much remains to be done. These regions are of interest almost solely from the geographical and geological standpoints; but they deserve careful investigation, not only that we may ascertain their actual present condition, but in order, also, that we may try to discover some clues to the past history of this interesting continent. Still, it must be said that the great features of the continent have been so fully mapped during the last half century that what is required now

is mainly the filling-in of the details. This is a process that requires many hands and special qualifications. All over the continent there are regions which will repay special investigation. Quite recently an English traveler, Mr Cowper, found not far from the Tripoli coast miles of magnificent ruins and much to correct on our maps. If only the obstructiveness of the Turkish officials could be overcome, there is a rich harvest for any one who will go to work with patience and intelligence. Even the interior of Morocco, and especially the Atlas mountains, are but little known. The French, in both Tunis and Algeria, are extending our knowledge southward.

EFFORTS OF THE POWERS

All the powers who have taken part in the scramble for Africa are doing much to acquire a knowledge of their territories. Germany especially deserves praise for the persistent zeal with which she has carried out the exploration of her immense territories in East and West Africa. The men she sends out are unusually well qualified for the work, capable not simply of making a running survey as they proceed and taking notes on country and people, but of rendering a substantial account of the geology, the fauna, the flora, and the economic conditions. Both in the French and the British spheres good work is also being done, and the map of Africa is being gradually filled up. But what we especially want now are men of the type of Dr J. W. Gregory, whose book on the Great Rift valley is one of the most valuable contributions to African geography ever made. If men of this stamp would settle down in regions like that of Mount Ruwenzori or Lake Rudolf or the region about lakes Bangweolo and Tanganyika, or in the Atlas or in many other regions that could be named, the gains to scientific geography, as well as to the economic interests of Africa, would be great. An example of work of this kind is seen in the discoveries made by a young biologist trained in geographical observation, Mr Moore, on Lake Tanganyika. There he found a fauna which seems to afford a key to the past history of the center of the continent, a fauna which, Mr Moore maintains, is essentially of a salt-water type. Mr Moore, I believe, is inclined to maintain that the ancient connection of this part of Africa with the ocean was not by the west, as Joseph Thomson surmised, but by the north, through the Great Rift valley of Dr Gregory, and he strongly advocates the careful examination of Lake Rudolf as the crucial test of his

theory. It is to be hoped that he or some one equally competent will have an opportunity of carrying out an investigation likely to provide results of the highest importance.

CLIMATE OF THE COUNTRY

But there are other special problems connected with this, the most backward and the most repellent of continents, which demand serious investigation—problems essentially geographical. One of the most important of these, from the point of view of the development of Africa, is the problem of acclimatization. The matter is of such prime importance that a committee of the Association has been at work for some years collecting data as to the climate of tropical Africa. In a general way we know that that climate is hot and the rainfall scanty; indeed, even the geographers of the ancient world believed that Central Africa was uninhabitable on account of its heat; but science requires more than generalities, and therefore we look forward to the exact results which are being collected by the committee referred to with much hope. We can only go to work experimentally until we know precisely what we have to deal with. It will help us greatly to solve the problem of acclimatization when we have the exact factors that go to constitute the climate of tropical Africa. At present there is no doubt that the weight of competent opinion—that is, opinion of those who have had actual experience of African climate and of those who have made a special study of the effects of that climate on the human constitution—is that, though white men, if they take due precautions, may live and do certain kinds of work in tropical Africa, it will never be possible to colonize that part of the world with people from the temperate zone. This is the lesson taught by generations of experience of Europeans in India.

So far, also, sad experience has shown that white people cannot hope to settle in Central Africa as they have settled in Canada and the United States and in Australia, and make it a nursery and a home for new generations. Even in such favorable situations as Blantyre, a lofty region on the south of Lake Nyasa, children cannot be reared beyond a certain age; they must be sent home to England, otherwise they will degenerate physically and morally. No country can ever become the true home of a people if the children have to be sent away to be reared. Still, it is true our experience in Africa is limited. It has been maintained that it might be possible to adapt Europeans to tropical

Africa by a gradual process of migration: Transplant southern Europeans to north Africa; after a generation or two remove their progeny further south, and so on, edging the succeeding generation further and further into the heart of the continent. The experiment—a long one it would be—might be tried; but it is to be feared that the ultimate result would be a race deprived of all those characteristics which have made Europe what it is.

HIDDEN ENEMIES

An able young Italian physician, Dr Sambon, has recently faced this important problem, and has not hesitated to come to conclusions quite opposed to those generally accepted. His position is that it has taken us centuries in Europe to discover our hidden enemies, the microbes of the various diseases to which northern humanity is a prey, and to meet them and conquer them. In Africa we have a totally different set of enemies to meet, from lions and snakes down to the invisible organisms that produce those forms of malaria, anæmia, and other diseases characteristic of tropical countries. He admits that these are more or less due to heat, to the nature of the soil, and other tropical conditions, but that if once we knew their precise nature and modes of working we should be in a position to meet them and conquer them. It may be so, but this is a result that could only be reached after generations of experience and investigation, and even Dr Sambon admits that the ultimate product of European acclimatization in Africa would be something quite different from the European progenitors. What is wanted is a series of carefully conducted experiments.

I have referred to the Blantyre highlands. In British East Africa there are plateaus of much greater altitude, and in other parts of Central Africa there are large areas of 4,000 feet and over above sea level. The world may become so full that we may be forced to try to utilize these lofty tropical regions as homes for white people when Canada and Australia and the United States become over populated. As one of my predecessors in this chair (Mr Ravenstein) tried to show at the Leeds meeting some years ago, the population of the world will have more than doubled in a century, and about 180 years hence will have quadrupled. At any rate, here is a problem of prime importance for the geographer of the coming century to attack. With so many energetic and intelligent white men all over Africa, it should not be difficult to obtain the data which might help toward its solution.

NORTH AMERICA

I have dwelt thus long on Africa, because it will really be one of the great geographical problems of the coming century. Had it been as suitable as America or Australia, we may be sure it would not have remained so long neglected and despised by the European peoples as it has done. Unfortunately for Africa, just as it had been circumnavigated, and just as Europeans were beginning to settle upon its central portion and trying to make their way into the interior, Columbus and Cabot discovered a new world—a world as well adapted as Europe for the energies of the white races. That discovery postponed the legitimate development of Africa for four centuries. Nothing could be more marked than the progress which America has made since its rediscovery 400 years ago, and the stagnation of Africa, which has been known to Europe since long before the beginning of history. During these 400 years North America at least has been very thoroughly explored. The two great nations which divide North America between them have their Government surveys, which are rapidly mapping the whole continent and investigating its geology, physical geography, and natural resources.

I need hardly tell an audience like this of the admirable work done by the survey of Canada under Sir William Logan, Dr Selwyn, and his successor, Dr George Dawson; nor should it be forgotten that under the lands department much excellent topographical work has been carried out by Captain Deville and his predecessors. Still, though much has been done, much remains to be done. There are large areas which have not as yet been roughly mapped. Within quite recent years we have had new regions opened up to us by the work of Dawson and Ogilvie on the Yukon, Dr Bell in the region to the south of Hudson bay, by the brothers Tyrrell in the barren lands on the west of the same bay, by O'Sullivan beyond the sources of the Ottawa, and by Low in Labrador.

But it is not so long since that Dr Dawson, in reviewing what remains to be done in the Dominion in the way of even pioneer exploration, pointed out that something like a million square miles still remained to be mapped. Apart from the uninhabitable regions in the north, there are, as Dr Dawson pointed out, considerable areas which might be turned to profitable agricultural and mining account of which we know little, such areas as these which have been recently mapped out on the south of Hud-

son bay by Dr Bell and beyond the Ottawa by Mr O'Sullivan. Although the eastern and western provinces have been very fully surveyed, there is a considerable area between the two lying between Lake Superior and Hudson bay which seems to have been so far almost untouched. A very great deal has been done for the survey of the rivers and lakes of Canada. I need hardly say that in Canada, as elsewhere in America, there is ample scope for the study of many problems in physical geography—past and present glaciation and the work of glaciers, the origin and régime of lake basins, the erosion of river beds, the oscillation of coast lines. Happily, both in Canada and the United States there are many men competent and eager to work out problems of this class, and in the reports of the various surveys, in the transactions of American learned societies, in scientific periodicals, and in separate publications, a wealth of data has already been accumulated of immense value to the geographer.

UNITED STATES

Every geologist and geographer knows the important work which has been accomplished by the various surveys of the United States, as well as by the various State surveys. The United States Coast Survey has been at work for more than half a century, mapping not only the coast but all the navigable rivers. The Lake Survey has been doing a similar service for the shores of the Great Lakes of North America. But it is the work of the Geological Survey which is best known to geographers—a survey which is really topographical as well as geological, and which, under such men as Hayden, King, and Powell, has produced a series of magnificent maps, diagrams, and memoirs of the highest scientific value and interest. Recently this survey has been placed on a more systematic basis, so that now a scheme for the topographical survey of the whole of the territory of the United States is being carried out. Extensive areas in various parts of the States have been already surveyed on different scales. It is to be hoped that in the future, as in the past, the able men who are employed on this survey work will have opportunities of working out the physiography of particular districts, the past and present geography of which is of advancing scientific interest. Of the complete exploration and mapping of the North American continent we need have no apprehension; it is only a question of time, and it is to be hoped that neither of the governments responsible will allow political

exigencies to interfere with what is really a work of national importance.

CENTRAL AND SOUTH AMERICA

It is when we come to Central and South America that we find ample room for the unofficial explorer. In Mexico and the Central American States there are considerable areas of which we have little or only the vaguest knowledge. In South America there is really more room now for the pioneer explorer than there is in Central Africa. In recent years the Argentine Republic has shown laudable zeal in exploring and mapping its immense territories, while a certain amount of good work has also been done by Brazil and Chile. Most of our knowledge of South America is due to the enterprise of Europeans and of North American explorers. Along the great river courses our knowledge is fairly satisfactory, but the immense areas, often densely clad with forests, lying between the rivers are almost unknown. In Patagonia, though a good deal has recently been done by the Argentine government, still in the country between Punta Arenas and the Rio Negro we have much to learn, while on the West Coast range, with its innumerable fjord-like inlets, its islands and peninsulas, there is a fine field for the geologist and physical geographer. Indeed, throughout the whole range of the Andes systematic exploration is wanted, exploration of the character of the excellent work accomplished by Whymper in the region around Chimborazo.

There is an enormous area lying to the east of the northern Andes and including their eastern slopes, embracing the eastern half of Ecuador and Colombia, southern Venezuela, and much of the country lying between that and northern Bolivia, including many of the upper tributaries of the Amazon and Orinoco, of which our knowledge is of the scantiest. Even the country lying between the Rio Negro and the Atlantic is but little known. There are other great areas in Brazil and in the northern Chaco which have only been partially described, such as the region whence the streams forming the Tapajos and the Paraguay take their rise, in Mato Grosso. A survey and detailed geographical and topographical description of the whole basin of Lake Titicaca is a desideratum.

In short, in South America there is a wider and richer field for exploration than in any other continent. But no mere rush through these little-known regions will suffice. The explorer

must be able not only to use his sextant and his theodolite, his compass, and his chronometer. Any expeditions entering these regions ought to be able to bring back satisfactory information on the geology of the country traversed, and of its fauna and flora, past and present. Already the revelations which have been made of the past geography of South America and of the life that flourished there in former epochs are of the highest interest. Moreover, we have here the remains of extinct civilizations to deal with, and although much has been done in this direction, much remains to be done, and in the extensive region already referred to the physique, the traditions, and the customs of the natives will repay careful investigation.

AUSTRALIA

The southern continent of Australia is in the hands of men of the same origin as those who have developed to such a wonderful extent the resources of Canada and the United States, and therefore we look for equally satisfactory results so far as the characteristics of that continent permit. The five colonies which divide among them the three million square miles of the continent have each of them efficient government surveys, which are rapidly mapping their features and investigating their geology; but Australia has a trying economic problem to solve. In none of the colonies is the water supply quite adequate; in all are stretches of desert country of greater or less extent. The center and western half of the continent are covered by a desert more waterless and more repellent than even the Sahara; so far as our present knowledge goes, one-third of the continent is uninhabitable. This desert area has been crossed by explorers, at the expense of great sufferings, in various directions, each with the same dreary tale of almost featureless sandy desert, covered here and there with spinifex and scrub, worse than useless. There are hundreds of thousands of square miles still unknown, but there is no reason to believe that these areas possess any features that differ essentially from those which have been found along the routes that have been explored.

There have been one or two well-equipped scientific expeditions in recent years that have collected valuable data with regard to the physical characteristics, the geology and biology of the continent; and it is in this direction that geography should look for the richest results in the future. There remains much to be done before we can arrive at satisfactory conclusions as to

the physical history of what is in some respects the most remarkable land area on the globe. Though the surface water supply is so scanty, there is reason to believe that underneath the surface there is an immense store of water. In one or two places in Australia, especially in western Queensland and in New South Wales, this supply has been tapped with satisfactory results; millions of gallons a day have been obtained by sinking wells. Whether irrigation can ever be introduced on an extensive scale into Australia depends upon the extent and accessibility of the underground water supply, and that is one of the geographical problems of the future in Australia. New Zealand has been fairly well surveyed, though a good deal remains to be done before its magnificent mountain and glacier system is completely known. In the great island of New Guinea both the British and the Germans are opening up the interiors of their territories to our knowledge, but the western and much larger portion of the island presents a large field for any explorer who cares to venture into its interior.

POLAR EXPLORATION

The marvelous success which has attended Dr Nansen's daring adventure into the Arctic seas has revived a widespread interest in polar exploration. Nansen may be said to have almost solved the North Pole problem—so far, at least, as the Old World side of the Pole is concerned. That some one will reach the Pole at no distant date is certain; Nansen has shown the way, and the legitimate curiosity of humanity will not rest satisfied till the goal be reached. But Arctic exploration does not end with the attainment of the Pole. Europe has done her share on her own side of the Pole; what about the side which forms the hinterland of North America, and especially of Canada? To the north of Europe and Asia we have the scattered groups of islands, Spitsbergen, Franz Josef Land, Nova Zembla, and the New Siberian islands. To the north of America we have an immense archipelago, the actual extent of which is unknown. Nansen and other Arctic authorities maintain that the next thing to be done is to complete exploration on the American side—to attempt to do for that half of the North Polar region what Nansen has done for the other half. It may be that the islands which fringe the northern shores of the new world are continued far to the north; if so, they would form convenient stages for the work of a well-equipped expedition. It may be that they do not go much far-

ther than we find them on our maps. Whatever be the case, it is important, in the interests of science, that this section of the polar area be examined; that as high a latitude as possible be attained; that soundings be made to discover whether the deep ocean extends all round the Pole.

It is stated that the gallant Lieutenant Peary has organized a scheme of exploring this area which would take several years to accomplish. Let us hope that he will be able to carry out his scheme. Meantime, should Canada look on with indifference? She has attained the standing of a great and prosperous nation. She has shown the most commendable zeal in the exploration of her own immense territory. She has her educational, scientific, and literary institutions which will compare favorably with those of other countries; her press is of a high order, and she has made the beginnings of a literature and an art of her own. In these respects she is walking in the steps of the mother country. But has Canada not reached a stage when she is in a position to follow the maternal example still further? What has more contributed to render the name of Great Britain illustrious than those enterprises which for centuries she has sent out from her own shores, not a few of them solely in the interests of science? Such enterprises elevate a nation and form its glory and its pride. Surely Canada has ambitions beyond mere material prosperity; and what better beginning could be made than the equipment of an expedition for the exploration of the seas that lie between her and the Pole? I venture to throw out these suggestions for the consideration of those who have at heart the honor and glory of the great Canadian Dominion.

THE ANTARCTIC REGIONS

Not only has an interest in Arctic exploration been revived, but in Europe at least an even greater interest has grown up in the exploration of the region around the opposite Pole of the earth of which our knowledge is so scanty. Since Sir James C. Ross' expedition, which was sent out in the year 1839, almost nothing has been done for Antarctic research. We have here to deal with conditions different from those which surround the North Pole. Instead of an almost landless ocean, it is believed by those who have given special attention to the subject that a continent about the size of Australia covers the South Polar region. But we do not know for certain, and surely, in the interests of our science, it is time we had a fairly adequate idea of what

are the real conditions. We want to know what is the extent of that land, what are its glacial conditions, what is the character of its geology, what evidence exists as to its physical and biological conditions in past ages? We know there is one lofty, active volcano. Are there any others? Moreover, the science of terrestrial magnetism is seriously impeded in its progress because the data in this department from the Antarctic are so scanty. The seas around this continent require to be investigated both as to their depth, their temperature, and their life. We have here, in short, the most extensive unexplored area on the surface of the globe.

For the last three or four years the Royal Geographical Society, backed by other British societies, has been attempting to move the home government to equip an adequate expedition to complete the work begun by Ross sixty years ago, and to supplement the great work of the *Challenger*; but though sympathy has been expressed for Antarctic exploration, and though vague promises have been given of support, the government is afraid to enter upon an enterprise which might involve the services of a few naval officers and men. We need not criticise this attitude; but the Royal Geographical Society has determined not to let the matter rest here. It is now seeking to obtain the support of public spirited men for an Antarctic expedition under its own auspices. It is felt that Antarctic exploration is peculiarly the work of England, and that if an expedition is undertaken it will receive substantial support from the great Australasian colonies, which have so much to gain from a knowledge of the physical condition of a region lying at their own doors and probably having a serious influence on their climatological conditions. Here, then, is one of the greatest geographical problems of the future, the solution of which should be entered upon without further delay. It may be mentioned that a small and well-equipped Belgian expedition has already started, mainly to carry out deep-sea search around the South Pole area, and that strenuous efforts are being made in Germany to obtain the funds for an expedition on a much larger scale.

OCEANOGRAPHY

But our science has to deal not only with the lands of the globe; its sphere is the whole of the surface of the earth and all that is thereon, so far at least as distribution is concerned. The department of oceanography is a comparatively new creation; in-

deed, it may be said to have come definitely into being with the famous voyage of the *Challenger*. There had been expeditions for ocean investigation before that, but on a very limited scale. It has only been through the results obtained by the *Challenger*, supplemented by those of expeditions that have examined more limited areas, that we have been able to obtain an approximate conception of the conditions which prevail throughout the various ocean depths—conditions of movement, of temperature, of salinity, of life. We have only a general idea of the contours of the ocean bed, and of the composition of the sediment which covers that bed. The extent of the knowledge thus acquired may be gauged from the fact that it occupies a considerable space in the fifty quarto volumes—the *Challenger* publications—which it took Dr John Murray twenty years to bring out.

What islands are to the ocean, lakes are to the land. It is only recently that these interesting geographical features have received the attention they deserve.

Rivers are of not less geographical interest than lakes, and these have also recently been the subject of special investigation by physical geographers. I have already referred to Professor Davis' study of a special English river system. The work in the English lake district by Mr Marr, spoken of in connection with Dr Mill's investigations, was mainly on the hydrology of the region. Both in Germany and in Russia special attention is being given to this subject, while in America there is an enormous literature on the Mississippi alone, mainly, no doubt, from the practical standpoint, while the result of much valuable work on the St Lawrence is buried in Canadian official publications.

THE COMPASS IN MODERN NAVIGATION

By G. W. Littlehales,

U. S. Hydrographic Office

Transoceanic navigation, with all that it has been to the commerce of the world and the development of the civilization of the nineteenth century, rests upon the magnetic needle of the mariner's compass. None but those who may estimate the effect of the sudden loss of the earth's magnetism will ever fully know the extent of the influence of the compass in human affairs.

Throughout the history of ocean navigation it has remained preeminent among nautical instruments; and today, by the side of the chronometer and sextant, it is scarcely less important than it was when it constituted the navigator's sole equipment. The later instruments have contributed to precision in the use of the compass and to precise navigation in general, but they have in no sense supplanted it or greatly affected the degree of its fundamental importance.

Up to the era of iron ships the management of the mariner's compass was as simple as the surveyor's, being influenced by the earth's magnetism alone; but with the growth of the application of steam propulsion to modern ships and the employment of iron and steel in their construction it was found that every ship herself becomes a great magnet like the earth is, although of lesser intensity.

It has long been known that the earth acts upon the magnetic needle somewhat as a bar magnet does, and that it has definite poles of magnetic strength and a magnetic field surrounding it which may be represented in general by lines of magnetic intensity issuing from one pole and proceeding to the other by curved paths to which a freely suspended magnetic needle will everywhere set itself tangent. For more than a century it has been customary among geomagneticians to represent the elements of the direction and intensity of the earth's magnetism as manifested at its surface by lines conceived to be drawn upon the surface of the globe. The lines passing through all places where the angle between the plane of the astronomical meridian and the vertical plane passing through a freely suspended magnetic needle is the same are called lines of equal magnetic declination or, among mariners and surveyors, lines of equal variation of the compass. These lines issue from one magnetic pole and pass by curved paths to the other and through the geographical poles of the earth. The lines which are conceived to be drawn through all places where the angle between the direction of a freely suspended needle and the plane of the horizon is the same are called lines of equal magnetic inclination or dip. They gird the earth in circumferences parallel to the magnetic equator, somewhat the same as the parallels of latitude with reference to the geographical equator. The magnetic equator is the line passing through every point at which the freely suspended needle lies in a horizontal plane. As we travel from the magnetic equator toward the northern magnetic pole the needle inclines more and

more, the north end tending downwards until the pole is reached, when the needle assumes a vertical direction. As we travel toward the southern magnetic pole the same takes place with the south end of the needle.

Similar results may be obtained by carrying a small needle through the magnetic field of a bar-magnet. At the neutral band it will be parallel to the bar, while, as either end is approached, the dip toward the Pole becomes more and more; and as with the bar-magnet, which has a magnetic field that varies in intensity from point to point, so with the earth, whose magnetic field is powerful near the Poles and steadily moderates in strength as the magnetic equator is approached. There is thus a third set of lines passing through all points where the magnetic intensity is the same. These are known as isodynamic lines or lines of equal magnetic intensity. In general contour they follow the lines of equal inclination or dip.

These different systems of lines representing the magnetic elements have not on the earth that symmetry and regularity which they would present around a steel bar; but, on the contrary, they often pursue serpentine courses with many a bend and loop; and since the values of the magnetic elements are not fixed either as to time or locality, they shift their positions hourly, daily, monthly, yearly, and through centuries. These changes are all believed to be periodic and, with the exception of the secular change, are of such small amplitude that they do not affect the use of the compass on the seas where commerce is carried on. So that for purposes of navigation, the terrestrial magnetic lines may be drawn so as to hold good for several years from a given epoch.

A freely suspended magnetic needle dipping, as it does, everywhere except on the magnetic equator, is of no value to guide a ship. The compass needle must be horizontal. This condition is attained in practice by putting a small sliding counterpoise on the needle to overcome the downward pull of the earth's magnetism, or by floating the compass-card in a mixture of water and alcohol. It is, therefore, only the horizontal component of the earth's magnetism that gives steadiness to the needle of the compass and influences its direction.

If a wooden ship, with no metal other than the copper in her frame, were to sail around the world, her compass would experience only those magnetic phases that result from the influence of the earth's magnetism—more or less steadiness, according to

the varying amount of the horizontal component of the intensity of the terrestrial magnetic field, and a variation of the compass of larger or smaller amount according to geographical position—the ship herself would exert no influence whatever. But, in modern navigation, instead of guiding a vessel having no magnetic influence whatever over the globe—a great magnet whose magnetic elements are known—the mariner's compass is employed in guiding a steel vessel, which is a great magnet, whose magnetic elements are ever varying and capricious, over the globe, a greater magnet.

If a bar-magnet be brought into a horizontal position under a compass-needle that has assumed a steady position under the influence of the earth's magnetism, the compass-needle will immediately move and assume a position which is the resultant of the joint action of the earth and the bar-magnet; and with every change in the azimuth or inclination of the bar-magnet the compass-needle will assume a new resultant position. This is analogous to the joint action of the magnetism of the earth and the iron ship on the mariner's compass, only the influence of the ship is vastly complicated by the existence, along with her permanent magnetic elements, of the ever-varying magnetic effects resulting from the inductive action upon the "soft" iron of the ship, of the fields of the earth's magnetism, and the ship's permanent magnetism.

If a cylinder of pure wrought iron that has not been hammered and is entirely free from magnetism be held vertically in our latitude the upper end instantly becomes a south and the lower a north pole. If it be reversed, the magnetism also reverses, so that the upper and lower ends are still as they were before—a south and a north pole, respectively. When it is held horizontally in the meridian the end toward the north becomes a north pole, while that toward the south becomes a south pole; and when it is revolved slowly or rapidly in azimuth, the foci of magnetic polarity move with the fidelity of a shadow, until when the cylinder points east and west, all the side facing the north is pervaded by north magnetism, and all facing the south by south magnetism. Again, let us conceive the hull of a ship to be like the cylinder of pure wrought-iron and as susceptible of magnetic induction in being steered over its ever-changing courses as the cylinder is when turned into different positions. Then, as the ship steers north, in the northern magnetic hemisphere, the bow will become the center of north polarity and the stern

that of south polarity. As she gradually changes course to the eastward, so will the north focus shift to the port bow, the south focus to the starboard quarter, and the neutral line dividing them, which while the ship headed north was athwartship, will now become a diagonal from starboard bow to port quarter. When the ship heads east all the starboard side is pervaded with south polarity, the port with north, and the neutral line takes a general fore-and-aft direction. Continuing to change course to the southward, the poles and neutral line continue their motion in the opposite direction, until at the south the conditions at north are repeated, but this time it is the stern that is a north pole, while the bow is a south pole. At west the conditions at east prevail, only that it is now the starboard side that has north polarity and the port side south polarity. And this transient induction in both the cylinder and the ideal ship is solely due to the effect of the earth's magnetic field in which they move.

Leaving now the *ideal* or "soft" iron ship and passing to the consideration of the *actual* ship, which is built of many beams and frames that have been bent, hammered, and twisted in fashioning them for the construction, we find that the structure, although still containing many "soft" iron pieces that become magnets when lying in the magnetic meridian and lose their magnetic qualities when turned at right angles to that plane, has acquired characteristics that make it as permanent and well defined a magnet as the steel bar, with poles and neutral line as in the bar, but located according to the direction, with reference to the magnetic meridian, in which the ship's keel lay during the course of her construction.

An iron ship, with her frames, plating, decks, beams, stanchions, shafts, engines, smoke-pipes, yards, and masts, is not a simple magnet like a steel bar, but a network of magnets having the characteristics of a simple magnet growing out of many and diverse and reactionary influences within the hull. However complex the network of magnets may be, yet, for purposes of analytical investigation to reach results to enable the mariner to allow for the influence of the ship's magnetism upon the compass, its effect may be considered as taking place in three cöordinate axes, namely, fore-and-aft, athwartship, and vertically downward, with the pivot of the compass needle as the origin.

Almost all the structural iron of a ship is symmetrically arranged with reference to the vertical plane through the keel, so that for any piece on the starboard side another is generally

found similarly disposed on the port side; and the problem is simplified to pairs of parallel forces, each pair having its resultant parallel to one of the cöordinate axes. The effect of every magnetic particle, whether of permanent or induced magnetism, may be reduced to this condition. If the sum total of all the magnetic forces parallel to each cöordinate axis be transferred to it, and the whole be conceived to be concentrated upon the north point of the compass-needle, the entire magnetic power of the ship may be compared to that of three imaginary compound-magnets—one laid horizontally in the axis of X; the second, also horizontally, in the axis of Y, and the third, vertically, in the axis of Z. By steaming around a circle in the open sea and observing the compass bearing of the sun with the ship's head on equidistant compass courses, and also, at the same times, the astronomical bearings of the sun, the magnetic effect of the ship—that is, of the three imaginary compound-magnets in the axes of X, Y, and Z—which causes the needle to deflect from the magnetic meridian by different angles at the different headings, can be immediately found, if the variation of the compass due to the geographical locality is known. As the ship makes a complete circle in azimuth, the north end of the needle is drawn sometimes to the right hand of the magnetic meridian and sometimes to the left hand; in the former case the deflection is called east deviation and in the latter west deviation. A table of these deflections, serially arranged, is called a table of deviations of the compass. The harmonic analysis of such a table of deviations consists in representing each of the elementary magnets, whose effects contribute to make up the imaginary compound-magnets, as a separate disturbing cause whose effect upon the compass needle may be represented by a constant multiplied by a simple harmonic function of the compass-azimuth of the ship's head. Adding together the effects of the different disturbing causes, thus represented, and placing them equal to the deviation observed on a certain heading of the ship, a conditional equation may be formed for each of the headings upon which the deviation was observed.

From such a series of conditional equations normal equations may be found by the method of least squares, and from them the harmonic constants which represent the elementary disturbing magnets. Thus it is that from the effect an intelligent comprehension of the cause may be gained.

With these coefficients a navigator may compute beforehand

the value of the deviation to which his compass will be subject on any heading of the ship; but in making long cruises and passing into different magnetic latitudes they require unceasing attention, because some of them represent the effects of the induction of the earth's magnetic field upon the "soft" iron of the ship, and as the ship sails the ocean she passes through ever-varying fields of terrestrial magnetism. Her own magnetism is also undergoing continual, though small, changes due to the wrenching and straining of the ship by the action of the sea. Yet, by examining thoroughly into the harmonic coefficients and by considering the known values of the elements of the earth's magnetism, a careful navigator may predict a table of deviations for his ship and compass in any part of the world.

He will then understand and be prepared for such changes in the ship's magnetism as arise from the heeling of the ship, from change in geographical position, and from alteration in the course after the ship has remained for a long time on one heading, and he may navigate his vessel with the confidence and security that he would have in a wooden ship, for he can at any time correct the course steered by the compass so that the magnetic course actually made good may be laid down upon the chart or used in the calculation of the ship's reckoning, he can correct bearings of the land by the amount of deviation due to the direction of the ship's head at the time they were taken, and if he wishes to shape a course for a port, having found by calculation or from the chart the correct magnetic course to be made good, he can so apply the deviation as to obtain the compass course to be steered.

In many modern ships the deviations are largely reduced by introducing magnets into positions near the compass to compensate for the effects of the ship's magnetism. The analysis of the table of deviations shows that the polar forces acting in the ship may be represented by imaginary magnets, and it is, therefore, certain from well known laws of magnetic action that the effects of these disturbing forces may be neutralized by introducing real magnets whose forces have the same magnitudes but act in the opposite directions.

The proceedings of the British Association at Toronto were admirably reported by the local press, the daily reports of the *Globe*, together with a finely illustrated supplement, aggregating nearly 150 columns, or the equivalent of an octavo volume of 550 pages of long primer.

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